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RESEARCH ARTICLE

Improving growth, and productivity of faba bean cultivars grown under drought stress conditions by using arbuscular mycorrhizal fungi in sandy soil

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Abstract

Two field experiments were carried out during the 2019-20 and 2020-21 seasons in private farm at west, El-Minia Governorate, Egypt, to evaluate the effect of using arbuscular mycorrhizal fungi (AMF) on promoting the efficiency faba bean cultivars cultivated in sandy soil to resist drought stress under drip irrigation system. The treatments of the experiment were composed of three irrigation treatments (I_{100}: full-irrigation, I_{75}: moderate drought, and I_{50}: severe drought), two inoculations [+] with AMF and [-] without AMF, and three faba bean cultivars (Giza-843, Nubaria-1, and Misr-1). Strip-split plot design in RCBD with three replications was used. The results indicate that (I_{50}) treatment significantly decreased leaf area index, No. of branches plant^{-1}, No. of leaves plant^{-1}, plant height, No. of pods plant^{-1}, 100-seed weight, No. of days from sowing to maturity, seed yield, and land use efficiency (LUE); increased water productivity (WP), economic water productivity (EWP), NPK%, and seeds crude protein SCP%, relative to (I_{100}) treatment, in both seasons. Inoculation with AMF significantly increased all studied traits of faba bean plants and improved nutrient and water uptake under drought-stress conditions. AMF was increased seed yield by 19.34 and 24.19% compared to un-inoculation in the 1st and 2nd seasons, respectively. Giza-843 *cv*. gave the highest values of plant height, No. of pods plant^{-1}, No. of days to maturity, seed yield, land use efficiency, WP, EWP, and tolerance to drought stress. The 1st and 2nd order interactions were significant in most traits.

Keywords: Faba bean; Drought tolerance indices; Economic water productivity; Mycorrhiza; Land efficiency.

1. Introduction

Egyptian agriculture faces several challenges to encounter food security such as rapid growth of the human population, avoiding a deficiency of available water resources, expected climatic changes, etc. Thus, horizontal and vertical expansion in Egyptian agriculture is urgently needed to reduce the gap between production and consumption. Legumes crops are a worthy source of fundamental nutrients for the human diet because they contain essential amino acids, minerals, and proteins as well as complex carbohydrates, and it's the second food crop after cereals worldwide (Abobatta *et al*., 2021, and Yannan *et al*., 2022). Among legumes crops, faba bean (*Vicia faba* L.) is one of the utmost important popular pulse food used in Egypt and worldwide due to its containing of 35% protein, 45% carbohydrate, and 2 % fat for seeds and its ability to fix atmospheric nitrogen (Gomaa and Afifi, 2021). Also, faba bean consumes the largest water than other legumes and is more drought-prone (Kenawy *et al*., 2022). In 2020, the cultivated area of faba bean in Egypt reached 58120 feds which produced 88109 tons with an average dry seed of about 1.52 tons fed^{-1} (FAO, 2020). Faba bean cultivars exhibit different responses in the production of seed yield when

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exposed to drought stress, and the Giza-843 cultivar was more tolerant to drought stress than other cultivars (Desoky *et al*., 2020). So, it is important to evaluate the potential of cultivars of faba bean under different irrigation levels by several indices, based on the loss of yield under stress conditions (Sharifi *et al*., 2021).

The most common form of mycorrhiza is the arbuscular mycorrhiza fungi (AMF), which means "Fungus Root", and Fungi coexist with the roots of most crops and fungal hyphae, thereby, becoming an essential factor in improving soil quality, enhancing productivity, and its high adaptation to local conditions (Milton *et al*., 2021). AMF is a vital part of soil microorganisms because it raises plant resistance to drought and improves the water use efficiency of crops by increasing the surface root area in the soil and supporting alternative physiological pathways (Abdoulaye *et al*., 2022). Inoculation of plants with AMF resulting increased crop yields by 23.0% owing to the increase in plant growth and nutrient uptake, photosynthesis, and drought stress resistance (Wu *et al*., 2022), improved soil structure (Youssef *et al*., 2017), and promoted crop quality and productivity (Begum *et al*., 2019).

Egypt is placed in an arid and semi-arid area, water scarcity and its use efficiency are considered essential factors that directly affect the productivity of many crops globally (Orabi *et al*., 2021), and crops need water for all physiological processes i.e., photosynthesis, nutrient uptake, and other metabolic processes, and about 400-500 liter of water is necessary for the production of 1 Kilo from plant dry matter (Attri *et al*., 2022). Arable land in Egypt is considered one of the world's most intensive agricultural systems, which is estimated at 3% of the total area of Egypt and the rest is desert (Salama *et al*., 2017). Limited water resources and few arable lands resulted in hindering ambitious expansion plans globally (Darwish *et al*., 2013), agriculture is the hugest water consumer where estimated at 70% of the total renewable freshwater resource worldwide (WWAP, 2014). Faba bean is grown in Egypt in sandy soils and its more sensitive to drought than other field crops, consequently exhausting great amounts of water, which negatively impacts plants' physiology and their productivity via drought, which in turn leads to a deficiency of food security and economic losses (El-Saadony *et al*., 2021). Drought stress has harmful effects on the growth and development of faba bean plants by disturbing the physiological and biochemical processes in the plant, i.e., reduces the photosynthetic rate, relative water contents, and transpiration rate (Begum *et al*., 2019) thus, reducing productivity (Ashine and Bedane, 2022). According to Kazai *et al*. (2019) noticed that water stress led to a decrease in number of pods plant^{-1} (53%), seeds pod^{-1} (9.7%), harvest index (49%), and seed yield (58%). Several studies on faba bean pointed out that water deficit stress caused a reduction in plant height, leaf area index, No. of branches plant^{-1}, No. of leaves plant^{-1}, number of pods plant^{-1}, 100-seed weight, seed yield, and the highest WUE and protein content in seeds of faba bean (Said *et al*., 2018; Ibrahim *et al*., 2020; Orabi *et al*., 2021; Abo-Alhassan *et al*., 2022). Drought tolerance indices and seed yield have been together used to identify cultivars appearing consistent perform under drought stress conditions. The present study was designed to study the impact of inoculation with mycorrhiza (AMF) on promoting the efficiency of faba bean cultivars cultivated in sandy soil to obtain maximum productivity and resist drought stress conditions under a drip irrigation system.

2. Materials and methods

Two field experiments were conducted during the two winter seasons of 2019-20 and 2020-21 in private farm at west Samalout, El-Minia Governorate, Egypt to evaluate the effect of using arbuscular mycorrhizal fungi (AMF) to promote the efficiency of faba bean cultivars grown in sandy soil to resist water stress. Soil analysis of the experimental site is classified as sandy (i.e., 88.7% sand, 5.2% silt, and 6.1 clay), with a pH of 7.8, EC 2.0 ds m^{-1}, and organic matter of 0.26 % as well as available each of N 2.4, P 3.0, and K 34.1 mg kg^{-1}, as mean over the two seasons (according to A.O.A.C, 1995). The agro-meteorological data for the experimental location during the two growing seasons 2019-20 and 2020-21 were obtained from the weather station of the Central Laboratory for Agricultural Climate (Table 1).

2.1. Experimental treatments and design

The experimental design used was a strip split-plot with 3 replications. The total number of experimental plots was 54 plots. Three irrigation treatments (100, 75, and 50% of ETc) were distributed in the vertical plots, two AMF were allocated in the horizontal plots (AMF_1: with inoculation and AMF_2: without un-inoculation), while three faba bean cultivars (Giza-843, Nubaria-1, and Misr-1) were occupied in sub- sub plot.

2.2. Irrigation treatments

The drip irrigation system was used, drip lateral had emitters spaced 30 cm apart with an actual discharge rate of 4 liters h^{-1}, where water was added every 5 days by applying the specified irrigation requirements (IR). Total irrigation water (m^3 fed^{-1}) was calculated from the meteorological data of (CLAC) depending on the method of (Penman, 1984). The amounts of irrigation water applied were 1560 (full-irrigation), 1170 (moderate drought), and 780 m^3 fed^{-1} (severe drought), calculated as 100, 75, and 50% of ETc, respectively (as the mean over the two seasons). The crop water requirements (ETc) were calculated using the crop coefficient according to the equation as follows:

$$ETc = ETo \times Kc$$

Where :

ETc= Crop evapotranspiration (mm day^{-1}).

ETo = Reference evapotranspiration (mm day^{-1}).

Kc = Crop Coefficient.

The amount of irrigation water applied for faba bean plants at each irrigation level was computed based on the following equation, according to Allen et al. (1998):

$$IWA = \left[\frac{A \times ETc \ \times Ii}{Ea \ \times 1000} + LR\right]$$

where:

IWA= Irrigation water applied (m^3), A= Plot area (m^2), ETc= Crop water requirments (mm day^{-1}), Ii= Intervals between irrigation (day), Ea= Irrigation system's efficiency (assumed to be 85% of total applied water), and LR= Leaching requirements (m^3).

2.3. Isolation of AMF and inoculum preparation

The mycorrhizal spores (Glomous sp) were obtained from the rhizosphere of fertile soil grown with the onion at the Talla village, El-Minia, Egypt. Mycorrhizal spores were isolated by the wet sieving and pouring technique according to the method Pacioni (1992). Mixed spores of AM-fungi were prepared after propagation. At planting, the inoculants were mixed with a sticker such as Arabic gum solution and added to the seeds of the faba bean cultivars which spread on a clean plastic sheet under shading before sowing at a rate of 10 g of inoculant with 1 kg $seeds^{-1}$, coating the seeds and air-dried for 2 hours before planting and then directly irrigation.

2.4. Cultivation

All cultivars were obtained from Food Legumes Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt. The seeds of faba bean cultivars were planted in ridges at distances of 0.60 m and 0.30 m spacing between plants at the rate of one seed $hill^{-1}$ (each sub-plot area was 10.5 m^2 (1/400 fed) consisting of 5 ridges × 3.5 m length × 0.60 m width). All cultivars were planted on the 25th and 28th of October in the 1st and 2nd seasons, respectively.

2.5. Agricultural operations

Inorganic fertilizers i.e., Nitrogen, Phosphorous, and potassium were applied to soil as follows, superphosphate (15.5% P_2O_5) was applied during soil preparation at a rate of 150 kg fed^{-1}, potassium sulfate (48% K_2O) was added after 4 weeks from sowing at a rate of 50 kg fed^{-1} and ammonium nitrate (33.5% N) was added as starter dose before the first irrigation (Mohaya) at a rate of 15 kg N fed^{-1}.

Maize was the preceding summer crop in both seasons. All other agricultural practices of faba bean cultivation were done as recommended by the Ministry of Agriculture.

2.6. Estimated characters and drought indices

- ***Vegetative growth characters:*** A representative sample of 10 plants from each treatment at 100 days from planting was randomly taken for measuring leaf area index (LAI), number of branches $plant^{-1}$, and number of leaves $plant^{-1}$.
  Leaf area index (LAI) = leaf area $plant^{-1}$(cm^2) ÷ ground area $plant^{-1}$ (cm^2)
- ***Seed yield and its attributes:*** At harvest time, ten plants from each plot were taken to determine plant height (cm), 100-seeds weight (g), and number of pods $plant^{-1}$. The whole plot was harvested and left for air drying until the moisture content of seeds reached 12%, then weighted (kg) and converted to ardab fed^{-1} (1 ardab =155 kg) to estimate seed yield.
- ***Number of days from sowing to maturity****:* Days taken to mature 95% of pods were estimated on the basis of whole plots.
- ***Water indices i.e., water productivity (WP) kg m^{-3} and economic water productivity (EWP) L.E m^{-3}:*** It was calculated using the following equations:
  WP (kg m^{-3}) = Seed yield (kg fed^{-1}) ÷ Water applied (m^3 fed^{-1}) (Molden, 1997).

  $$\text{EWP (L.E m}^{-3}) = \frac{\text{Value of Seed yield (L.E fed}^{-1})}{\text{Water applied (m}^3\text{ fed}^{-1})}$$ (Molden, 1997)

- The average of price seed faba bean was L.E 1878 $ardab^{-1}$ (Bulletin of Statistical Cost Production and Net Return, 2019-20).
- ***Land Use efficiency (LUE) kg seeds day^{-1}:*** was determined as the following equation:
  $$\text{LUE} = \frac{\text{Seed yield (kg fed}^{-1})}{\text{Number of days from sowing to maturity}}$$
  (El-Karamity *et al*., 2015)

- ***Macronutrients (NPK%) in seed, and Seed crude protein% (SCP):*** Total N was determined using the micro kjeldahl method (Page *et al*., 1982). The protein% in seeds was expressed as multiplying the total N% by a factor of 6.25 according to A.O.A.C (1990). The phosphorus% was determined by colorimetric method using a spectrophotometer (Page *et al*., 1982), and the potassium% was measured by a Flame photometer (Chapman and Pratt, 1982).
- ***Drought tolerance indices:*** calculations of drought tolerance indices for cultivars as shown in Table 2.

2.7. Statistical analysis

Data were statistically analyzed according to Snedecor and Cochran (1990). Mean values were compared to each other using the Least Significant Differences (LSD) test procedure at $P \leq 0.05$ probability using the Co-Stat soft program (2004).

Table 1. Mean monthly agro-meteorological data at the experimental site during the two seasons.

Month	Air temperature ºC			GDD	Relative Humidity %	Wind speed (m s^{-1})	Sunshine (hour)	ETo (mm d^{-1})	Rain (mm)	Solar Radiation (MJ/m^2/day)
	Max.	Min.	Mean							
2019-20 season										
October	33.31	18.64	25.43	667.43	44.71	2.96	11.46	6.08	1.40	19.70
November	28.28	14.29	20.50	498.00	46.36	2.21	10.74	3.93	0.00	16.10
December	20.72	8.15	13.51	297.91	64.83	2.49	10.38	2.53	36.50	14.15
January	18.13	5.13	10.89	216.69	64.82	2.48	10.57	2.52	1.10	14.64
February	20.73	6.82	13.12	267.38	61.19	2.18	11.19	3.25	23.60	17.80
March	25.10	9.38	16.61	394.01	53.46	2.79	12.01	5.11	6.90	21.31
2020-21 season										
October	34.16	19.45	26.25	692.85	46.83	3.30	11.47	6.46	0.00	19.87
November	25.27	13.27	18.74	445.20	59.00	2.63	10.74	3.55	2.00	15.74
December	22.98	10.06	15.67	364.87	54.54	2.29	10.38	2.98	0.20	13.70
January	21.76	7.59	13.70	303.80	54.20	2.22	10.6	3.00	0.40	15.15
February	22.46	7.71	14.41	294.28	52.55	2.52	11.2	3.71	2.50	18.48
March	25.36	9.66	17.07	408.27	48.07	3.05	12.0	5.37	15.60	22.84

Max.: Maximum, Min.: Minimum, GDD: Growing Degree Days or accumulated daily heat units

$GDD = [(T_{Max.} + T_{Min.}) \div 2] - T_{Base}$ (T Base=3.9 ºC)

Table 2. Calculating drought tolerance indices for studied cultivars based on seed yield using the following relationships.

Tolerance indices	Equation	Reference
Yield reduction rate%	$YRR = 1- (Y_S / Y_N) \times 100$	Kazai *et al*. (2019)
Stress susceptibility index	$SSI = [1-(Y_S/Y_N)] / [1- (\bar{Y}_S/\bar{Y}_N)]$	Fischer and Maurer (1978)
Mean productivity index	$MP = (Y_N + Y_S) / 2$	Rosielle and Hamblin (1981)
Yield stability index	$YSI = Y_S / Y_N$	Bouslama and Schapaugh (1984)
Golden mean	$GOL = (Y_N+Y_S) / (Y_N-Y_S)$	Moradi *et al*. (2012)
Stress tolerance index	$STI = (Y_N \times Y_S) / (\bar{Y}_N)^2$	Fernandez (1992)

YS and YN denote the mean yield of cultivars under drought stress and full-irrigation conditions, respectively.
ȲS and ȲN denote the average yield of all cultivars under drought stress and full-irrigation conditions, respectively.

3. Results and discussion

3.1. Effect of different treatments on vegetative growth traits and seed yield and its attributes

The results in Tables 3 and 4 exhibited the effect of three irrigation treatments, three faba bean cultivars, and two arbuscular mycorrhizal fungi (AMF) and their interaction on vegetative growth traits and yield and its components during the 2019-20 and 2020-2021 seasons.

3.1.1. Effect of irrigation treatments

Results revealed that the best treatment when plants are grown under full irrigation is (I_{100}), which gives the most astounding estimations of vegetative growth traits and yield and its components. While the lowest value of such characteristics was more obvious when (ETc) reached up to 50% (I_{50}) in both seasons. Generally, vegetative growth traits and seed yield related-traits increased when the supplied water was increased from 50 to 100% of ETc. At 50 and 75% of ETc, decreased LAI by (18.43 and 7.86%) and (17.68 and 7.75%), number of branches plant^{-1} by (29.33 and 10.34%) and (29.76 and 13.14%), plant height by (16.69 and 5.47%) and (16.49 and 6.13%), number of leaves plant^{-1} by (21.52 and 7.60%) and (22.33 and 9.68%), No. of pods plant^{-1} by (47.11 and 15.56%) and (47.62 and 16.53%), 100-seed weight by (19.75 and 7.17%) and (18.51 and 6.39%), No. of days from sowing to maturity by (8.38 and 4.65%) and (7.23 and 3.91%), seed yield by (46.06 and 21.42%) and (40.40 and 20.25%), and land use efficiency by (41.11 and 17.57%) and (35.76 and 17.01%), compared with irrigation level of 100% of ETc, in the 1st and 2nd seasons, respectively. Similar outcomes were recorded by El-Gabry and Morsi (2019) indicating that drought severely affects all agronomic traits of faba bean. Early maturity (138.71 and 140.26 days) and a reduction in LAI (3.32 and 3.40) under severe drought conditions, were more important for plants to avoid severe water stress than those to full irrigation in both seasons, respectively. Our results were supported by Abid *et al*. (2017) and Ouji *et al*. (2017) who revealed that the shortest No. of days to maturity were gained under drought-stress conditions. Water deficit leads to deleterious effects on all studied traits through reduction of water flow from the xylem to the different cells, a decrease in cell division, reduced efficiency photosynthetic and ion uptake, thus, deterrence physiological processes needed for plant growth, which in turn effects on yield and its related traits. These results agree with those of Ibrahim *et al*. (2020), Paul *et al*. (2021), Sary *et al*. (2021), Yousry *et al*. (2021), Abo-Alhassan *et al*. (2022) and Ashine and Bedane (2022).

3.1.2. Effect of AMF inoculum

With the respect to AMF, the data reported revealed that the plants inoculated with AM fungi under sandy soil conditions induced significant increases in all vegetative growth criteria and seed yield and its attributes of faba beans than those plants un-inoculated with AMF during the two seasons (Tables 3 and 4). The increases in LAI, No. of branches plant^{-1}, No. of leaves plant^{-1}, plant height, No. of pods plant^{-1}, 100-seed weight, No. of days from sowing to maturity, seed yield and land use efficiency with mycorrhiza inoculation [+], were (7.26 and 7.14%), (32.58 and 35.79%), (22.14 and 24.12%), (15.76 and 17.12%), (5.09 and 2.32%), (1.53 and 1.60%), (19.34 and 24.19%), and (17.30 and 22.41%) higher than those attained without inoculation [-] respectively, in both seasons. Similarly, El-Mansy *et al*. (2021) pronounced that inoculated plants with AMF significantly attained the highest vegetative growth traits, and yield and its components of faba bean than un-inoculated during the two seasons. AM fungi-mediated growth parameters promotion through improving water and nutrient uptake (especially P), widening the absorptive surface area provided by the extended fungal hyphae and increment N-fixation (Hashem *et al*., 2014; Begum *et al*., 2019).

Table 3. Vegetative growth traits, plant height, and No. of pods plant^{-1} of faba bean cultivars as affected by irrigation treatments, and mycorrhiza, during the 2019-20 and 2020-21 seasons.

Treatments	Leaf area index (LAI)		Number of branches plant^{-1}		Number of leaves plant^{-1}		Plant height (g)		Number of pods plant^{-1}	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation treatments (I)										
I_{100} Full-irrigation	4.07	4.13	3.58	3.73	34.06	35.11	94.31	96.66	13.50	14.28
I_{75} Moderate drought	3.75	3.81	3.21	3.24	31.47	31.71	89.15	90.73	11.40	11.92
I_{50} Severe drought	3.32	3.40	2.53	2.62	26.73	27.27	78.57	80.72	7.14	7.48
LSD 0.05 (I)	0.05	0.02	0.24	0.13	0.72	0.39	0.90	0.83	0.41	0.35
Mycorrhiza (AMF)										
[-] without	3.58	3.64	2.67	2.71	27.69	27.99	86.38	87.85	9.90	10.34
[+] with	3.84	3.90	3.54	3.68	33.82	34.74	88.30	90.89	11.46	12.11
LSD 0.05(AMF)	0.08	0.05	0.14	0.03	0.42	0.09	0.80	1.21	0.31	0.59
Cultivars (C)										
Giza-843	3.32	3.38	3.06	3.12	30.43	30.82	90.88	92.69	11.87	12.39
Nubaria-1	3.84	3.92	3.87	3.92	36.10	36.46	87.63	89.99	9.20	9.85
Misr-1	3.98	4.03	2.39	2.55	25.73	26.82	83.51	85.43	10.96	11.45
LSD 0.05 (C)	0.05	0.02	0.10	0.09	0.30	0.27	1.00	0.51	0.23	0.18
LSD 0.05 for interactions										
I × AMF	NS	NS	0.16	0.19	0.48	0.57	1.12	0.90	0.29	0.07
I × C	0.09	0.03	0.17	0.16	0.51	0.49	1.74	0.88	0.40	0.32
AMF × C	NS	0.02	0.14	0.13	0.42	0.40	NS	NS	0.32	0.26
I × AMF × C	NS	0.04	0.24	0.22	0.73	0.67	NS	NS	0.56	0.45

Also, AM fungi improve yield and its components as it provides an adequate supply of mineral nutrients and accelerates the water and nutrient transfer from root to the stem, the increment in active nodule formation, the dry weight of the plant, and thereby increasing seed yield and its attributes. This is in agreement with Wu *et al*. (2022) who declared that the application of AMF increased crop yields by boosting shoot biomass due to the amelioration of plant nutrition, photosynthesis, and stress resistance in the rainfed field. Many previous studies have indicated that inoculation with AMF imparts other benefits to plants, including enhanced photosynthesis rate, production of secondary metabolites like phytohormones, amino acids, vitamins, mineralization, and solubilization processes, the osmotic adjustment under stress and increased resistance against abiotic and biotic stresses as well as improving water use efficiency (Pereira *et al*., 2019; Komeil and Badry, 2021; Yousry *et al*., 2021).

Overall, AMF is one of the most effective and environmental-friendly management approaches for enhancing legume crop productivity against drought stress and their ability to transform plant waste into stable soil carbon for other soil fungi through having a portion rich in carbon that can remain for decades in the soil as well as it is the best important biological association that improves the growth and productivity of plants (Milton *et al*., 2021; Yannan *et al*., 2022), and a suitable AM strain for soil and crop may be successful to cater plant needs for nutrients, water, and the substitute of agrochemicals (Kuila and Ghosh, 2022).

Table 4. 100-Seed weight, number of days to maturity, seed yield, land use efficiency, and water productivity of faba bean cultivars as affected by irrigation treatments, and mycorrhiza during the 2019-20 and 2020-21 seasons.

Treatments	100-seed weight (g)		Number of days to maturity (days)		Seed yield (ardab fed^{-1})		Land Use Efficiency (kg seeds day^{-1})		Water Productivity (kg m^{-3})	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation treatments (I)										
I_{100}Full- irrigation	72.76	73.38	151.34	151.19	9.01	9.53	9.22	9.76	0.90	0.95
I_{75}Moderate drought	67.54	68.69	144.30	145.28	7.08	7.60	7.60	8.10	0.94	1.01
I_{50}Severe drought	58.39	59.80	138.71	140.26	4.86	5.68	5.43	6.27	0.96	1.13
LSD 0.05 (I)	1.02	0.68	0.30	0.40	0.28	0.22	0.27	0.24	0.03	0.03
Mycorrhiza (AMF)										
[-] without	64.58	65.42	143.69	144.42	6.36	6.78	6.82	7.23	0.84	0.91
[+] with	67.87	66.94	145.89	146.73	7.59	8.42	8.00	8.85	1.02	1.15
LSD 0.05(AMF)	0.87	0.61	1.13	0.74	0.17	0.08	0.08	0.14	0.01	0.002
Cultivars (C)										
Giza-843	58.43	59.85	146.01	146.69	7.48	8.02	7.88	8.42	1.00	1.09
Nubaria-1	79.17	77.71	143.28	143.76	6.28	6.89	6.74	7.39	0.84	0.93
Misr-1	61.08	60.99	145.08	146.28	7.19	7.90	6.62	8.32	0.96	1.07
LSD 0.05 (C)	0.34	0.52	0.34	0.45	0.12	0.08	0.11	0.09	0.02	0.01
LSD 0.05 for interactions										
I × AMF	NS	NS	0.39	0.35	NS	NS	NS	0.15	0.04	0.02
I × C	0.58	0.91	0.37	0.32	0.20	0.14	0.21	0.16	0.03	0.02
AMF × C	NS	NS	0.19	0.20	0.16	0.11	0.17	0.13	0.02	0.01
I × AMF × C	NS	NS	0.40	0.36	NS	0.19	NS	0.23	0.04	0.02

3.1.3. Faba bean cultivars performance

Concerning the performance of cultivars during the two seasons, data presented in the same table, indicate significant differences among the three cultivars of faba bean. Maximum LAI was recorded by cv. Misr-1 (3.98 and 4.03), whereas the minimum LAI was observed for cv. Giza-843 (3.32 and 3.38) in the 1st and 2nd seasons, respectively. The highest No. of branches plant^{-1} (3.87 and 3.92) and No. of leaves plant^{-1} (36.10 and 36.46) were obtained from cv. Nubaria-1, while the lowest values in these traits were detected from cv. Misr-1 in the first and second seasons, respectively. Giza-843 cv. exhibited the highest values for plant height (90.88 and 92.69 cm), No. of pods plant^{-1} (11.87 and 12 39 pods), took No. of days from sowing to maturity (146.01 and 146.69 days), seed yield (7.48 and 8.02 ardab fed^{-1}), and land use efficiency (7.88 and 8.42 kg seeds day^{-1}) as compared to other cultivars in 1st and 2nd seasons, respectively. Differences in growth traits and seed yield and its attributes among cultivars may be mainly due to their differential expressively of certain genes during autogenetic processes. The superiority of the Giza-843 cv. in seed yield in both seasons may be more likely attributed to the increases in plant height, No. of pods plant^{-1} and days to maturity which directly in turn on seed yield. Indeed, an increase in LUE was expected because corresponds with seed yield fed^{-1} (El-Karamity *et al.*, 2015). The genetic makeup of the Giza-843 cv. promoted the growth efficiency of plants, which reflected positively on leaf growth and seed filling period than other cultivars (Sheha *et al.*, 2020). Generally, producing several branches plant^{-1} ought not to be considered a good trait since lateral branches are not as productive as the main stem (Etemadi *et al.*, 2018). Similar variations, among cultivars, were reported by Tawfik *et al.* (2018), EL-Sherbeni *et al.* (2021), El-Safy *et al.* (2021), Yousry *et al.* (2021) and Mohammed *et al.* (2022).

3.1.4. Interactions effect

In Tables 5 and 6, the data reveal that interaction between irrigation treatments (I) and mycorrhiza

(AMF) had a significant effect on all traits in both seasons, except LAI and 100-seed weight in the two seasons, seed yield in 2nd season, and LUE in 1st season. The combination of (I_{100}×with AMF) produced the maximum values of all traits, while the minimum values on the same traits were recorded from (I_{50}×without AMF). The effect of interaction between I×C seemed to be significant for all growth traits and yield in both seasons. The best interaction was found between Giza-843 *cv.* and 100% of ETc which gave the greatest values for No. of leaves plant^{-1}, plant height, No. of pods plant^{-1}, No. of days from sowing to maturity, seed yield, and LUE in both seasons. Likewise, Nubaria-1 *cv.* and I_{100} recorded the highest values for No. of branches plant^{-1} and 100-seed weight in both seasons. Misr-1 cv. and I_{100} achieved the highest value for LAI in both seasons. Regarding the interaction effect of ([+]AMF×C) on vegetative growth, and yield and its attributes significant increases were obtained in most traits using AMF and cultivars compared to non-inoculation cultivars ([-]AMF×C) in both seasons, except for plant height and 100-seed weight in both season, and LAI in the 1st season, and No. of days from sowing to maturity in the 2nd season. The highest recorded value of No. of branches plant^{-1} (4.52 and 4.58 branches), and No. of leaves plant^{-1} (40.66 and 41.08 leaves) was obtained from inoculation of the Nubaria-1 *cv.* with AMF in both seasons, respectively. Data also show inoculation of the Giza-843 *cv.* with AMF achieved greater values for No. of pods plant^{-1} (12.83 and 13.43 pods), seed yield (8.29 and 8.91 ardab fed^{-1}), and LUE (8.66 and 9.29 kg seeds day^{-1}) in the 1st and 2nd seasons, respectively, and days to maturity (147.27 days) in the first season only. The maximum value for LAI (4.13) has been obtained from inoculation Misr-1 *cv.* with AMF in the 2nd season. The effect of interaction among the studied three factors was significant in No. of branches plant^{-1}, No. of leaves plant^{-1} and No. of pods plant^{-1} in the two seasons, LAI, seed yield, and LUE in the second season, and No. of days from sowing to maturity in the first season. Inoculation of Nubaria-1 *cv.* by AM fungi and irrigation at (I_{100}) gave the highest value of No. of branches plant^{-1} (5.22 and 5.30 branches) and No. of leaves plant^{-1} (45.54 and 46.10 leaves) in both seasons, respectively. Among cultivars studied the Giza-843 gets the heaviest seed yield (10.98 ardab fed^{-1}), and LUE (11.03 kg seeds days^{-1}) when treated Giza-843 with AM fungi under full-irrigation treatment (I_{100}) in the second season. In the same previous interaction, the Giza-843 *cv.* took from sowing to maturity (155.23 days) in the first season. Inoculation Misr-1 *cv.* with AMF and at 100% ETc scored the maximum value of LAI (4.43) in the second season.

3.2. Effect of different treatments on water indices, macronutrients (NPK%) in seeds and seed crude protein% (SCP%)

3.2.1. Effect of irrigation treatments

Under drought stress conditions significantly increased WP, EWP, NPK% and SCP% compared with the full-irrigation (I_{100}) in both seasons (Tables 4 and 7). Exposure faba bean plants to severe drought (I_{50}) increased WP (0.96 and 1.13 kg m^{-3}), EWP (11.69 and 13.67 L.E m^{-3}), N (4.07 and 4.11%), P (0.53 and 0.55%), K (1.74 and 1.77%), and crude protein (25.44 and 25.68%), while full-irrigation produced the lowest values in these traits. Drought-stressed plants exhibit an increase in WP than that received 100% of ETc, because of their more efficient water consumption and water loss reduction due to osmotic regulation. Also, Desoky *et al*. (2020) indicated that deficit-irrigation can improve WUE due to less applied water and more yield. Plants under moderate and severe drought stress conditions exhibit higher crop water productivity than under full-irrigation plants (Mansour *et al*., 2021). Also, EWP is a measure to estimate the value of economic earnings by the consumption of the unit amount of water (L.E m^{-3}). These results are in harmony with those of Kahramanoglu *et al*. (2020) who demonstrated that irrigation economic productivity and irrigation economic efficiency are significantly different and meaningful for different crops and must it's considered in sustainable agricultural planning. Furthermore, irrigation management can positively impact the profitability of bean productivity (Saleh *et al*., 2018), and in areas where irrigation water is the limiting factor to crop production, increasing water productivity via deficit irrigation is often more economically profitable for a farmer than maximizing yield (Yousry *et al*., 2021). Under full-irrigation treatment (I_{100}), the SCP was decreased by 13.99 and 14.21%, compared with severe drought treatment (I_{50}) in both seasons, respectively. Seeds crude protein% increased gradually with decreasing irrigation levels (Tawfik *et al*., 2018; Paul *et al*., 2021). Protein is a good indicator of plant tolerance to water deficit, as full irrigation results in hydrolysis and catabolism in proteins and releases free amino acids, ammonia, and proline (Fayed *et al.*, 2018), also plays critical physiological roles in the early stages from plant growth and enhances its stress resistance through accumulating large quantities of soluble protein and other metabolites to improve cell sap concentration, which can keep cell turgidity and prevent excessive plasma drought (Abid *et al*., 2017; Kenawy *et al*., 2022).

3.2.2. Effect of AMF inoculum

Compared with non-inoculated AMF, the WP, EWP, NPK%, and SCP% traits significantly improved by inoculating with AMF. In (Tables 4 and 7) cleared that both WP, EWP, NPK%, and SCP% of mycorrhizal faba bean plants fungi were more significant than those of non-mycorrhizal plants. Plants inoculation with AM fungi increased WP by (21.43 and 26.37%), EWP by (21.14 and 27.03%) N (8.29 and 7.63%), P (25.00 and 23.81%), K (3.80 and 3.73%), and SCP by (8.36 and 7.72%) as compared with non-treated with AMF, in the 1st and 2nd seasons, respectively. The symbiotic relationship between AMF and host plants played a beneficial role in increasing WUE by improving the rate of transport of macro and micronutrients to the plants and improving its resistance to water stress, subsequently more efficient water use. Plants inoculated with mycorrhiza recorded accumulated high protein content% (Sheteiwy *et al*., 2021). Mycorrhiza fungi inoculation increased protein and mineral ions contents compared with non-inoculated plants under drought stress (Sary *et al*., 2021).

3.2.3. Faba bean cultivars performance

Results display significant differences among the three tested cultivars of faba bean (Tables 4 and 7). The best values for the WP and EWP have occurred from the Giza-843 *cv.* than the Nubaria-1 *cv.* and this may be due to genetic superiority and drought tolerance. Nubaria-1 *cv.* significantly surpassed other cultivars and recorded the highest values for N (4.00 and 4.06%), P (0.48 and 0.50%), K (1.66 and 1.68%), and SCP% (25.02 and 25.40%) respectively, in both seasons. It might be attributed to the genetic constitution and the response of cultivars to environmental conditions. Similar variations, among cultivars, were reported by Abid *et al*. (2017), Tawfik *et al*. (2018) and El-Gabry and Morsi (2019). The performance of any cultivar depends on how its genetic traits interact with the environmental conditions, thus, high yields and better WUE can be done by using appropriate cultivars and optimizing water management, because the optimum water requirements are variable between different cultivars (Saleh *et al*., 2018), Therefore, cultivating the Giza-843 drought-tolerant cultivar is a preferred approach to improve WP, EWP, and enhance seed yield, especially in arid environments (Mansour *et al.*, 2021).

Table 5. Vegetative growth traits, plant height, and No. of pods plant^{-1} of faba bean cultivars as affected by the 1st and 2nd order interactions during the 2019-20 and 2020-21 seasons.

Treatments			Leaf area index (LAI)		Number of branches Plant^{-1}		Number of leaves plant^{-1}		Plant height (g)		Number of pods plant^{-1}	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation treatments (I) × Mycorrhiza (AMF)												
I_{100} Full-irrigation	[-] without		3.95	4.02	3.05	3.08	30.40	30.54	92.71	94.17	12.53	13.08
	[+] with		4.17	4.24	4.10	4.38	37.73	39.68	95.91	99.15	14.46	15.47
I_{75} Moderate drought	[-] without		3.63	3.65	2.67	2.71	27.74	27.97	88.32	89.91	10.79	11.30
	[+] with		3.88	3.95	3.74	3.78	35.20	35.44	89.97	91.55	12.02	12.53
I_{50} Severe drought	[-] without		3.17	3.28	2.28	2.35	24.94	25.45	78.13	79.47	6.38	6.65
	[+] with		3.47	3.50	2.79	2.87	28.53	29.09	79.01	81.96	7.90	8.31
LSD 5% for (I × AMF)			NS	NS	0.16	0.19	0.48	0.57	1.12	0.90	0.29	0.07
Irrigation treatments (I) × Cultivars (C)												
I_{75} Moderate drought		Giza-843	3.85	3.90	3.53	3.58	33.71	34.03	98.20	100.26	15.18	16.03
		Nubaria-1	4.10	4.18	4.37	4.44	39.56	40.05	93.67	96.71	11.52	12.13
		Misr-1	4.25	4.31	2.85	3.18	28.92	31.26	91.07	93.02	13.80	14.68
I_{75} Moderate drought		Giza-843	3.36	3.43	3.20	3.23	31.37	31.61	93.36	95.00	12.58	12.92
			3.86	3.93	4.07	4.11	37.49	37.77	90.14	92.15	9.95	10.85
		Misr-1	4.04	4.06	2.37	2.39	25.56	25.73	83.95	85.05	11.67	11.98
I_{50} Severe drought		Giza-843	2.75	2.81	2.46	2.55	26.22	26.81	81.09	82.82	7.86	8.21
		Nubaria-1	3.56	3.66	3.18	3.23	31.26	31.58	79.11	81.11	6.14	6.56
		Misr-1	3.66	3.72	1.96	2.07	22.72	23.46	75.53	78.22	7.41	7.68
LSD 5% for (I × C)			0.09	0.03	0.17	0.16	0.51	0.49	1.74	0.88	0.40	0.32
Mycorrhiza (AMF) × Cultivars (C)												
[-] without		Giza-843	3.16	3.21	2.59	2.64	27.13	27.46	89.82	90.95	10.92	11.34
		Nubaria-1	3.72	3.80	3.22	3.26	31.54	31.48	86.85	88.86	8.54	9.08
		Misr-1	3.87	3.92	2.20	2.24	24.40	24.68	82.48	83.92	10.23	10.62
[+] with		Giza-843	3.47	3.54	3.53	3.60	33.73	34.18	91.94	94.43	12.83	13.73
		Nubaria-1	3.96	4.03	4.52	4.58	40.66	41.08	88.42	91.29	9.86	10.62
		Misr-1	4.09	4.13	2.58	2.85	27.06	28.95	84.54	86.94	11.69	12.27
LSD 5% for (AMF × C)			NS	0.02	0.14	0.13	0.42	0.40	NS	NS	0.32	0.26
Irrigation treatments (I) × Mycorrhiza (AMF) × Cultivars (C)												
I_{100} Full-irrigation	[-] without	Giza-843	3.73	3.78	3.04	3.11	30.28	30.77	96.03	97.29	14.02	14.61
		Nubaria-1	4.02	4.06	3.51	3.57	33.57	33.99	92.80	94.44	10.43	17.44
		Misr-1	4.11	4.18	2.62	2.55	27.34	26.85	89.30	90.78	13.15	10.95
	[+] with	Giza-843	3.96	4.01	4.02	4.04	37.14	37.28	100.37	103.22	16.33	13.32
		Nubaria-1	4.18	4.29	5.22	5.30	45.54	46.10	94.53	98.97	12.60	13.69
		Misr-1	4.38	4.43	3.07	3.81	30.49	35.67	92.83	95.25	14.45	15.66
I_{75} Moderate drought	[-] without	Giza-843	3.22	3.26	2.72	2.75	28.04	28.25	92.87	94.13	11.74	12.20
		Nubaria-1	3.70	3.75	3.19	3.22	31.33	31.54	88.90	91.37	13.42	13.63
		Misr-1	3.96	3.95	2.12	2.16	23.84	24.12	83.19	84.24	9.50	10.20
	[+] with	Giza-843	3.50	3.59	3.67	3.71	34.69	34.97	93.85	95.87	10.40	11.50
		Nubaria-1	4.01	4.10	4.95	5.00	43.65	44.00	91.37	92.93	11.12	11.49
		Misr-1	4.12	4.17	2.61	2.62	27.27	27.34	84.70	85.86	12.22	12.47
I_{50} Severe drought	[-] without	Giza-843	2.54	2.60	2.01	2.05	23.07	23.35	80.57	81.44	7.00	7.20
		Nubaria-1	3.43	3.60	2.96	3.00	29.72	30.00	78.85	80.24	8.73	9.21
		Misr-1	3.54	3.64	1.86	2.01	22.02	23.07	74.97	76.75	5.70	6.08
	[+] with	Giza-843	2.95	3.01	2.91	3.04	29.37	30.28	81.60	84.21	6.58	7.04
		Nubaria-1	3.68	3.71	3.40	3.45	32.80	33.15	79.36	81.98	6.44	6.68
		Misr-1	3.78	3.79	2.06	2.12	23.42	23.84	76.08	79.70	8.37	8.68
LSD 5% for (I × AMF × C)			NS	0.04	0.24	0.22	0.73	0.67	NS	NS	0.56	0.45

Table 6. 100-Seed weight, number of days to maturity, seed yield, land use efficiency, and water productivity of faba bean cultivars as affected by the 1st and 2nd order interactions during the 2019-20 and 2020-21 seasons.

Treatments			100-seed weight (g)		Number of days to maturity (days)		Seed yield (ardab fed^{-1})		Land Use Efficiency (kg seeds day^{-1})		Water Productivity (kg m^{-3})	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation treatments (I) × Mycorrhiza (AMF)												
I_{100} Full-irrigation	[-] without		71.10	72.60	149.29	149.15	8.37	8.77	8.70	9.12	0.83	0.87
	[+] with		74.41	74.16	153.40	153.22	9.64	10.29	9.73	10.40	0.96	1.02
I_{75} Moderate drought	[-] without		66.19	68.04	143.54	144.38	6.56	6.82	7.08	7.32	0.87	0.90
	[+] with		68.88	69.33	145.06	146.18	7.61	8.37	8.12	8.87	1.01	1.11
I_{50} Severe drought	[-] without		56.47	58.95	138.22	139.72	4.18	4.74	4.69	5.26	0.83	0.94
	[+] with		60.31	60.65	139.20	140.80	5.54	6.62	6.16	7.28	1.10	1.32
LSD 5% for (I × AMF)			NS	NS	1.16	0.21	NS	NS	NS	0.15	0.05	0.03
Irrigation treatments (I) × Cultivars (C)												
I_{75} Moderate drought		Giza-843	62.83	65.49	152.76	151.93	9.71	10.06	9.84	10.25	0.97	1.00
		Nubaria-1	89.21	87.66	149.80	150.07	8.27	8.63	8.56	8.93	0.82	0.86
		Misr-1	66.23	67.01	151.18	151.57	9.05	9.90	9.25	10.12	0.90	0.98
I_{75} Moderate drought		Giza-843	59.15	60.88	145.79	147.17	7.57	7.95	8.06	8.38	1.01	1.05
		Nubaria-1	81.45	83.35	142.27	142.80	6.23	6.95	6.79	7.54	0.82	0.92
		Misr-1	62.01	61.83	144.87	145.87	7.43	7.89	7.95	8.38	0.98	1.04
I_{50} Severe drought		Giza-843	53.32	53.16	139.47	140.97	5.16	6.05	5.73	6.64	1.02	1.20
		Nubaria-1	66.86	62.12	137.77	138.42	4.34	5.08	4.88	5.70	0.86	1.01
		Misr-1	54.99	54.12	138.90	141.40	5.08	5.91	5.67	6.47	1.01	1.17
LSD 5% for (I × C)			0.58	0.91	0.60	0.77	0.20	0.14	0.21	0.16	0.03	0.02
Mycorrhiza (AMF) × Cultivars (C)												
[-] without		Giza-843	56.74	58.97	144.74	145.50	6.68	7.12	7.10	7.55	0.88	0.96
		Nubaria-1	60.12	60.72	142.48	142.88	5.98	6.19	6.46	6.68	0.79	0.82
		Misr-1	77.53	76.80	143.84	144.88	6.46	7.02	6.91	7.47	0.85	0.94
[+] with		Giza-843	80.81	78.61	147.27	147.88	8.29	8.91	8.66	9.29	1.11	1.21
		Nubaria-1	59.48	60.49	144.08	144.68	6.58	7.58	7.02	8.09	0.88	1.04
		Misr-1	62.67	61.48	146.32	147.68	7.92	8.78	8.33	9.17	1.07	1.19
LSD 5% for (AMF × C)			NS	NS	0.49	NS	0.16	0.11	0.17	0.13	0.02	0.02
Irrigation treatments (I) × Mycorrhiza (AMF) × Cultivars (C)												
I_{100} Full-irrigation	[-] without	Giza-843	61.16	64.72	150.30	149.53	8.85	9.13	9.13	9.47	0.88	0.91
		Nubaria-1	87.32	86.78	148.30	148.70	7.91	8.20	8.27	8.58	0.79	0.82
		Misr-1	64.81	66.31	149.30	149.23	8.37	8.97	8.68	9.32	0.83	0.89
	[+] with	Giza-843	64.50	66.26	155.23	154.33	10.56	10.98	10.54	11.03	1.05	1.09
		Nubaria-1	91.10	88.53	151.30	151.43	8.64	9.05	8.85	9.27	0.86	0.90
		Misr-1	67.64	67.70	153.67	153.90	9.72	10.84	9.81	10.92	0.96	1.08
I_{75} Moderate drought	[-] without	Giza-843	57.60	60.05	145.10	146.60	6.88	7.12	7.35	7.54	0.91	0.94
		Nubaria-1	80.33	82.46	141.60	141.93	6.00	6.27	6.57	6.84	0.79	0.83
		Misr-1	60.64	61.61	143.93	144.60	6.78	7.08	7.30	7.59	0.90	0.94
	[+] with	Giza-843	60.69	61.70	146.47	147.73	8.27	8.77	8.77	9.21	1.10	1.16
		Nubaria-1	82.57	84.23	142.93	143.67	6.45	7.63	7.00	8.24	0.85	1.01
		Misr-1	63.38	62.05	145.80	147.13	8.08	8.70	8.59	9.16	1.07	1.15
I_{50} Severe drought	[-] without	Giza-843	51.47	52.13	138.83	140.37	4.30	5.11	4.80	5.67	0.85	1.02
		Nubaria-1	64.94	61.16	137.53	138.00	4.02	4.12	4.53	4.63	0.80	0.82
		Misr-1	52.99	53.56	138.30	140.80	4.22	5.00	4.73	5.50	0.84	0.99
	[+] with	Giza-843	55.17	54.19	140.10	141.57	6.02	6.98	6.65	7.64	1.19	1.39
		Nubaria-1	68.77	63.08	138.00	138.83	4.65	6.05	5.22	6.76	0.92	1.20
		Misr-1	56.98	54.68	139.50	142.00	5.94	6.81	6.60	7.44	1.18	1.35
LSD 5% for (I × AMF × C)			NS	NS	0.84	NS	NS	0.19	NS	0.23	0.04	0.03

3.2.4. Interactions effect

For severe drought treatment (I_{50}) and AMF and their effect on WP and EWP, tables 6 and 8 showed the interaction treatment (I_{50} and inoculation with AMF) was significant for WP, EWP, N%, and SCP% where record WP (1.10 and 1.32 kg m^{-3}), EWP (15.93 and 19.91 L.E m^{-3}), N (4.27 and 4.31%), and SCP% (26.68 and 26.93%) in both seasons, respectively, and record K% (1.77%) in the 2nd season only. Concerning interaction effects between I×C, exhibited significant variances for WP and EWP in both seasons, and SCP% in 2nd season only (Tables 6 and 8). The *cv*.Giza-843 ×50% of ETc, resulted in the highest values for WP (1.02 and 1.20 kg m^{-3}), and EWP (12.42 and 14.56 L.E m^{-3}), while the *cv*.Nubaria-1 ×100% of ETc, produced the lowest values for WP (0.82 and 0.86 kg m^{-3}) and EWP (9.96 and 10.25 L.E m^{-3}) in the two seasons, respectively. The *cv*.Nubaria-1 when exposed to severe drought (I_{50}) recorded the highest value of SCP% (27.48), K (1.82%) in the 2nd season, and P (0.56%) in the 1st season.For the *cv*. Giza-843, tables 6 and 8 displays that the interaction with mycorrhiza significantly increased WP, EWP, N%, P%, and in both seasons. It is clear that the *cv*.Giza-843 inoculated with AM fungi scored the highest values of WP (1.11 and 1.21 kg m^{-3}), EWP (14.49 and 16.81 L.E m^{-3}), and followed by the *cv*. Misr-1 with the same treatment in the 1st and 2nd seasons, respectively in tables 6 and 8.

Table 7. Economic water productivity, macronutrients (NPK%), and seeds crude protein% of faba bean cultivars as affected by irrigation treatments, and mycorrhiza during the 2019-20 and 2020-21 seasons.

Treatments	Economic water productivity (L.E m^{-3})		macronutrients % (NPK) in seeds: N%		P%		K%		Seeds crude protein %	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation treatments (I)										
I_{100} Full-irrigation	10.84	11.43	3.50	3.52	0.39	0.40	1.50	1.52	21.88	22.03
I_{75} Moderate drought	11.37	12.19	3.74	3.80	0.45	0.46	1.60	1.62	23.35	23.76
I_{50} Severe drought	11.69	13.67	4.07	4.11	0.53	0.55	1.74	1.77	25.44	25.68
LSD 0.05 (I)	0.36	0.36	0.05	0.05	0.02	0.02	0.03	0.01	0.24	0.24
Mycorrhiza (AMF)										
[-] without	10.22	10.95	3.62	3.67	0.40	0.42	1.58	1.61	22.61	22.94
[+] with	12.38	13.91	3.92	3.95	0.50	0.52	1.64	1.67	24.50	24.71
LSD 0.05 (AMF)	0.24	0.17	0.08	0.04	0.001	0.02	0.008	0.01	0.36	0.27
Cultivars (C)										
Giza-843	12.09	13.13	3.60	3.66	0.43	0.45	1.58	1.60	22.51	22.87
Nubaria-1	10.12	11.22	4.00	4.06	0.48	0.50	1.66	1.68	25.02	25.40
Misr-1	11.68	12.94	3.70	3.71	0.45	0.47	1.61	1.63	23.14	23.21
LSD 0.05 (C)	0.21	0.14	0.03	0.03	0.009	0.008	0.01	0.005	0.22	0.17
LSD 0.05 for interactions										
I × AMF	0.54	0.33	0.05	0.04	NS	NS	0.009	NS	0.48	0.21
I × C	0.26	0.24	NS	NS	0.02	NS	NS	0.009	NS	0.30
AMF × C	0.30	0.20	0.05	0.04	0.01	0.01	NS	NS	0.32	NS
I × AMF × C	0.57	0.34	NS	0.06	NS	NS	0.03	0.01	NS	0.42

On the other hand, inoculation of *cv*. Nubaria-1 with AMF realized the greatest values of N (4.18 and 4.21%) and P (0.54 and 0.55%) in both seasons, respectively, and SCP% gets 26.10 % in the first season. Regarding I+C+AMF interaction, generally *cv*. Giza-843 irrigated at 50% of ETc and inoculated with AMF gave the highest values of WP (1.19 and 1.39 kg m^{-3}) and EWP (14.49 and 16.81 L.E m^{-3}), followed by *cv*. Misr-1, in first and second seasons, respectively. On the other hand, the interaction among I_{50}+Nubaria-1+AMF attained the highest value of

P (1.74 and 1.79%) in both seasons, N (4.61%) in the 1st season, and SCP% 28.81% in the 2nd season.

Table 8. Economic water productivity, macronutrients (NPK %), and seeds crude protein% of faba bean cultivars as affected by the 1st and 2nd order interactions during the 2019-20 and 2020-21 seasons.

Treatments			Economic water productivity, LE m^{-3}		macronutrients % (NPK) in seeds: N%		P%		K%		Seeds crude protein %	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Irrigation treatments (I) × Mycorrhiza (AMF)												
I_{100} Full-irrigation	[-] without		10.08	10.48	3.38	3.39	0.33	0.35	1.46	1.49	21.11	21.19
	[+] with		11.61	12.37	3.62	3.66	0.44	0.45	1.54	1.56	22.65	22.88
I_{75} Moderate drought	[-] without		10.52	10.95	3.61	3.71	0.40	0.42	1.57	1.59	22.53	23.20
	[+] with		12.21	13.43	3.86	3.89	0.49	0.51	1.63	1.66	24.17	24.31
I_{50} Severe drought	[-] without		10.06	11.42	3.87	3.91	0.48	0.50	1.72	1.74	24.20	24.44
	[+] with		13.33	15.93	4.27	4.31	0.58	0.61	1.77	1.80	26.68	26.93
LSD 5% for (I × AMF)			0.54	0.33	0.05	0.04	NS	NS	0.009	NS	0.48	0.21
Irrigation treatments (I) × Cultivars (C)												
I_{75} Moderate drought		Giza-843	11.69	12.11	3.37	3.38	0.36	0.38	1.47	1.49	21.03	21.15
		Nubaria-1	9.96	10.25	3.70	3.75	0.41	0.43	1.53	1.56	23.10	23.44
		Misr-1	10.89	11.92	3.44	3.44	0.39	0.40	1.50	1.52	21.50	21.51
I_{75} Moderate drought		Giza-843	12.18	12.75	3.54	3.64	0.43	0.45	1.57	1.59	22.14	22.77
		Nubaria-1	9.99	11.16	4.00	4.04	0.46	0.48	1.64	1.66	24.98	25.28
		Misr-1	11.93	12.66	3.67	3.72	0.45	0.46	1.59	1.62	22.93	23.22
I_{50} Severe drought		Giza-843	12.42	14.56	3.90	3.94	0.50	0.53	1.70	1.72	24.36	24.69
		Nubaria-1	10.42	12.25	4.32	4.40	0.56	0.58	1.80	1.82	26.98	27.48
		Misr-1	12.24	14.22	4.00	3.98	0.52	0.55	1.73	1.76	24.99	24.88
LSD 5% for (I × C)			0.26	0.24	NS	NS	0.02	NS	NS	0.009	NS	0.30
Mycorrhiza (AMF) × Cultivars (C)												
[-] without		Giza-843	10.69	11.57	3.44	3.51	0.38	0.41	1.55	1.57	21.51	21.97
		Nubaria-1	9.60	9.88	3.83	3.91	0.42	0.44	1.63	1.65	23.95	24.47
		Misr-1	10.38	11.40	3.58	3.58	0.40	0.42	1.57	1.60	22.38	22.39
[+] with		Giza-843	13.50	14.70	3.76	3.80	0.48	0.49	1.61	1.63	23.51	23.77
		Nubaria-1	10.65	12.55	4.18	4.21	0.54	0.55	1.69	1.71	26.10	26.33
		Misr-1	12.99	14.47	3.82	3.84	0.50	0.52	1.64	1.66	23.90	24.02
LSD 5% for (AMF × C)			0.30	0.20	0.05	0.04	0.01	0.01	NS	NS	0.32	NS
Irrigation treatments (I) × Mycorrhiza (AMF) × Cultivars (C)												
I_{100} Full-irrigation	[-] without	Giza-843	10.66	10.99	3.22	3.23	0.30	0.33	1.43	1.44	20.09	20.20
		Nubaria-1	9.52	9.66	3.59	3.65	0.36	0.37	1.51	1.54	22.41	22.81
		Misr-1	10.07	10.80	3.33	3.29	0.33	0.34	1.45	1.48	20.82	20.55
	[+] with	Giza-843	12.72	13.22	3.51	3.53	0.41	0.43	1.51	1.53	21.97	22.10
		Nubaria-1	10.40	10.83	3.81	3.85	0.47	0.49	1.56	1.58	23.79	24.07
		Misr-1	11.70	13.05	3.55	3.60	0.44	0.45	1.54	1.56	22.18	22.47
I_{75} Moderate drought	[-] without	Giza-843	11.05	11.42	3.40	3.56	0.39	0.41	1.54	1.56	21.22	22.28
		Nubaria-1	9.63	10.06	3.84	3.91	0.41	0.43	1.61	1.63	24.01	24.45
		Misr-1	10.89	11.36	3.58	3.66	0.40	0.41	1.56	1.58	22.35	22.88
	[+] with	Giza-843	13.30	14.08	3.68	3.72	0.47	0.48	1.60	1.63	23.05	23.26
		Nubaria-1	10.35	12.25	4.15	4.18	0.51	0.53	1.66	1.68	25.96	26.10
		Misr-1	12.97	13.97	3.76	3.77	0.49	0.51	1.63	1.65	23.51	23.57
I_{50} Severe drought	[-] without	Giza-843	10.35	12.30	3.71	3.75	0.46	0.48	1.68	1.70	23.22	23.44
		Nubaria-1	9.65	9.92	4.06	4.18	0.50	0.52	1.76	1.78	25.41	26.15
		Misr-1	10.17	12.04	3.84	3.80	0.48	0.50	1.71	1.73	23.98	23.73
	[+] with	Giza-843	14.49	16.81	4.08	4.15	0.55	0.57	1.72	1.74	25.51	25.94
		Nubaria-1	11.19	14.57	4.57	4.61	0.63	0.65	1.84	1.86	28.54	28.81
		Misr-1	14.31	16.40	4.16	4.16	0.56	0.60	1.74	1.79	26.00	26.03
LSD 5% for (I × AMF × C)			0.57	0.34	NS	0.06	NS	NS	0.03	0.01	NS	0.42

Table 9. Estimation of different drought tolerance indices for the faba bean cultivars based on seed yield under full-irrigation, moderate and severe drought conditions (averaged over two seasons).

Cultivars (C)	Seed yield (ardab fed^{-1})			Yield reduction rate from non-stressed % (YRR)		Stress susceptibility index (SSI)		Mean productivity index (MP)		Yield stability index (YSI)		Geometric mean productivity (GMP)		Stress tolerance Index (STI)	
	Irrigation treatments (I)														
	I_{100}	I_{75}	I_{50}	I_{75}	I_{50}	I_{75}	I_{50}	I_{75}	I_{50}	I_{75}	I_{50}	I_{75}	I_{50}	I_{75}	I_{50}
	Average the two seasons														
Giza-843	9.89	7.76	5.61	21.54	43.28	1.10	1.00	8.83	7.75	0.78	0.57	8.76	7.45	0.893	0.646
Nubaria-1	8.45	6.59	4.71	22.01	44.26	1.10	1.02	7.52	6.58	0.78	0.56	7.46	6.31	0.648	0.462
Misr-1	9.48	7.66	5.50	19.20	41.98	0.95	0.98	8.57	7.49	0.81	0.58	8.52	7.22	0.845	0.607
Mean	9.27	7.34	5.27	20.92	43.17	1.05	1.00	8.31	7.27	0.79	0.57	8.60	3.63	0.795	0.572

I_{100}: Seed yield for full-irrigation *I_{75}: Seed yield for moderate drought* *I_{50}: Seed yield for severe drought*

3.3. Evaluation of faba bean cultivars by drought stress tolerant indices

To assess drought tolerance indices of three faba bean cultivars, YRR, SSI, MP, YSI, GML, and STI were calculated based on seed yield under full-irrigation (I_{100}), moderate (I_{75}), and severe drought conditions (I_{50}) Table 9. Results exhibit that the Giza-843 *cv*. attained the highest value of seed yield 9.89 ardab fed^{-1} under full-irrigation (I_{100}) conditions, followed by the Misr-1 *cv*. 9.48 ardab fed^{-1}. whereas the Nubaria-1 *cv*. recorded the lowest value of seed yield 8.45 ardab fed^{-1} and their yield reduction was 14.56% relative to the Giza-843 *cv*. Under drought stress conditions (I_{75} and I_{50}), and according to drought indices the Giza-843 *cv*. displayed the maximum values for YRR (21.54 and 43.28%), MP (8.83 and 7.75), GMP (8.76 and 7.45), and STI (0.893 and 0.646), indicating high yield under Y_N and Y_S, and scored Misr-1 *cv*. the highest values for YSI (0.81 and 0.58), and the lowest values for YRR (19.20 and 41.98%) and SSI (0.95 and 0.98) respectively.

Indeed, Misr-1 and Giza-843 cultivars were considered tolerant to drought stress because exhibited lower values of yield reduction rate (YRR) and stress susceptibility index (SSI), and higher values for YSI and STI, and realized the best seed yield under (I_{100}) and (I_{50}). In contrast, the Nubaria-1 *cv*. recorded the lowest values by MP, YSI, GOL, and STI indices under (I_{100}) and (I_{50}), and the highest values by YRR and SSI, indicating higher sensitivity to drought stress. A high STI indicates a high tolerance (Afiah *et al*., 2016). These results are in agreement with those obtained by Kazai *et al.* (2019), El-Hashash and EL-Agoury (2019) and Sharifi *et al*. (2021) evident that STI, GMP, and MP indices had a high correlation with grain yield under both full-irrigation and drought stress conditions and are appropriate to identify cultivars with high grain yield and low sensitivity to drought stress.

4. Conclusion

In conclusion, the combination of suitable cultivars *i.e*., (cv. Giza-843), inoculation with AM fungi as eco-friendly, and adding the highest level of irrigation water (1560 m^3 fed^{-1}) to enhance crop quality and quantity as well as minimize problems of water shortages, improve Water Use Efficiency, Economic Water Porductivity, and soil quality, and provide quality food and sustainable agriculture under sandy soil conditions and drip irrigation system in West, El-Minia Governorate.

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